極成層圏雲と上部対流圏の雲との関係 －ブロッキングの役割－

高麗正史[1]、佐藤薫[1]
[1] *東大院理*

The relationship between polar stratospheric clouds and upper tropospheric clouds -the role of blocking highs-

M. Kohma[1] and K. Sato[1]
[1] *Univ. of Tokyo*

Recent studies using satellite observations (e.g., Wang et al., 2008) reported that polar stratospheric clouds (PSCs) in the Antarctic are frequently observed simultaneously when upper tropospheric clouds (UCs) appear. Although previous studies suggest that tropospheric disturbances may connect between PSCs and UCs, the mechanism remains unclear. In this study, we examine statistically the frequency of cases when PSCs and UCs are simultaneously observed. Next, the role of tropospheric anticyclones in the simultaneousness is investigated. Cloud observations from CALIPSO and reanalysis (ERA-Interim) data are analyzed for the austral winters of 2007, 2008 and 2009, although the results of 2008 are mainly shown.

The right panel of Fig. 1 shows PSC or UC frequencies as a function of altitude. The relatively high frequency is observed in the altitude range of 14-20 km which corresponds to PSCs while UCs are mainly located below 9 km. To investigate how often PSCs and UCs are simultaneously observed, correlation coefficients between the time series of the cloud existence at two different altitudes are calculated (the left panel of Fig. 1). The correlation coefficients between clouds in 15-20 km are high. The clouds in 15-20 km are also positively correlated with those in 9-11 km. In contrast, correlation coefficients between clouds in 15-20 km and those below 8 km drop sharply to 0.2 or less. It is interesting note that clouds around 13 km are weakly correlated with those above and below. The tropospheric clouds with PSCs as shown by previous studies are likely corresponding to the clouds in the altitude range between 9 and 11 km.

Previous studies (e.g., Teitelbaum et al., 2001; Kohma and Sato, 2011) show that some PSCs are associated with anticyclonic potential vorticity (PV) anomalies near the tropopause. A composite of the relative longitude-altitude section of PSC/UC frequencies in June through August 2008 is plotted (Fig. 2). The reference longitude is determined where PV anomalies from the zonal mean are positively maximized in the zonal direction at 65°S on 300 K, and with their maximal values greater than 1.5 PVU. Significantly-high PSC/UC frequencies are observed not only below 12 km but also in the altitude range of 15-20 km around the reference longitude. Thus, the simultaneous appearance of PSC and UC is likely associated with the anticyclones near the tropopause.

To estimate the vertical extent of the temperature anomalies associated with the anticyclones near the tropopause, we calculate Rossby Height (H_{R}), which is defined as fL/N. In the winter lowermost stratosphere at 65°S, a typical H_{R} value is about 4 km assuming that $N = 0.02\ \mathrm{s}^{-1}$ and $L = 6000$ km. As the tropopause height is approximately 8 km, the tropospheric disturbances have significant amplitudes up to the altitude of 13 km. Thus, the tropospheric anticyclones are not responsible for the existence of PSCs in 15-20 km. Next, the vertical extent of the anticyclonic PV anomaly is examined using equivalent latitudes (dynamical latitudes defined based on PV). Figure 3 shows a geographical latitude-pressure section of the equivalent latitude at 60°W on August 2, 2008, when PSCs and UCs are simultaneously observed. An important feature is that the region with equivalent latitudes lower than 40° extends vertically up to 125 hPa (about 13 km) at a geographical latitude of 67°S. Taking 13 km as the top edge of the tropospheric disturbances (i.e., aier intrusion from lower latitudes), the vertical penetration is estimated to be 17 km. The anticyclonic disturbances associated with simultaneous appearance of PSCs and UCs have a quite large horizontal scale (~several thousand kilometers) (Fig. 2) and tall structure (Fig. 3). These features suggest the anticyclonic disturbances are blocking highs in the troposphere (e.g., Schwierz et al., 2004).

Following a methodology for detecting blocking highs suggested by Schwierz et al. (2004), we compare the longitudinal variations of the frequencies of blocking highs and of simultaneous observation of PSCs and UCs. The results for the austral winter of 2008 are shown in Fig. 4. The longitude range of high frequency of simultaneous occurrence PSCs and UCs (black line) accords well with that of high frequency of blocking highs (red line) in the longitude range of 110°W and 30°W. Furthermore, when the analyzed region is limited inside the polar vortex on 550 K (blue line), the frequency of blocking highs inside the vortex are more consistent with that of simultaneous occurrence of PSCs and UCs, in particular, in the longitude range between 120°E and 160°W in 2008. These characteristics are observed in the austral winters of 2007 and 2009.

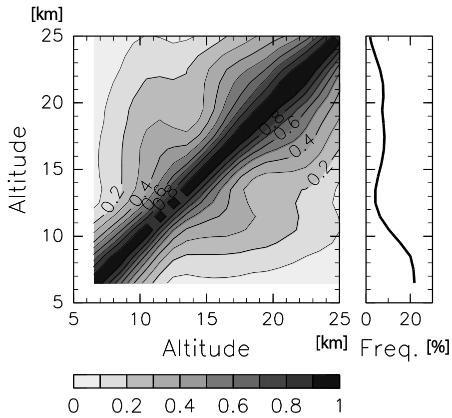

Figure 1: Correlation coefficients between the time series of PSC or UC existence at one altitude range and that at another altitude range in June through September 2008 (left). Right panel shows PSC or UC occurrence frequency (%) as a function of altitude.

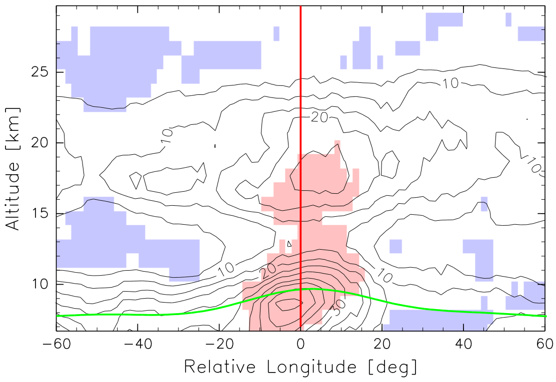

Figure 2: A composite of the relative longitude-altitude section of PSC or UC occurrence frequency in June through August 2008 with a reference longitude (red line) where PV anomalies are positive and maximized in the zonal direction at 65°S on $\theta = 300$ K, and their values are larger than 1.5 PVU. Contour intervals are 5%. Shaded are the regions with significant levels greater than 95%. A green thick curve indicates the dynamical tropopause (PV = 2 PVU).

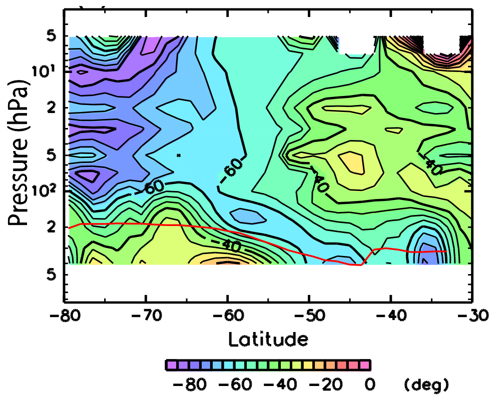

Figure 3: A geographical latitude and pressure section of equivalent latitude at 60°W on August 2 2008. A red curve shows dynamical tropopause (PV = 2 PVU).

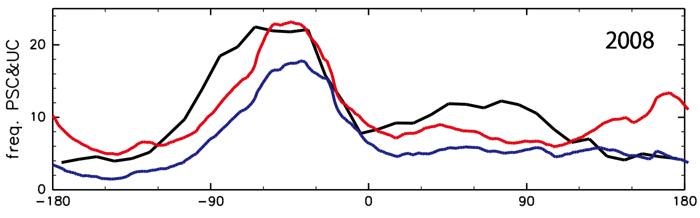

Figure 4: A black curve shows frequencies of simultaneous observations of PSCs in 18-20 km and UCs in 9-11 km as a function of longitude in June through September 2008. A red curve indicates frequencies of blocking highs to the south of 55°S. A blue curve indicates frequencies of blocking highs within the polar vortex on the 550K isentropic surface.

References

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